Envelope & Room Decisions

OBJECTIVE

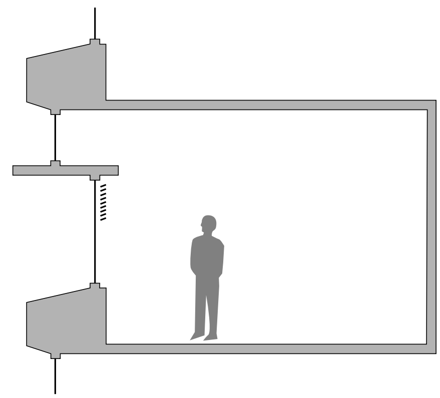
Design siting, massing, facade, windows, and interior to maximize daylight effectiveness, provide occupant comfort, and minimize glare.

- These decisions determine the potential for useful daylight and energy savings.
- Architectural decisions of this nature can influence the building's lifetime energy use more than mechanical and lighting decisions.

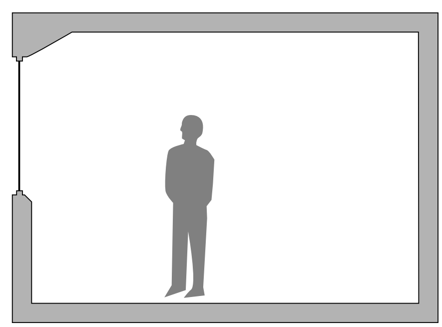
KEY IDEAS

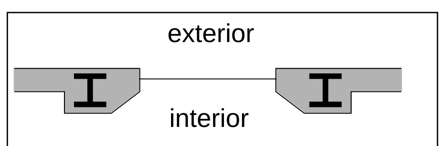
Building Form and Skin

- **Increase exposure to daylight.** The higher the skin-to-volume ratio, the greater percentage of floor space available for daylighting. Long and narrow footprints are preferable to square ones, up to a limit, although a high skin-to-volume ratio may mean a heating or cooling penalty. North and south exposures are generally preferred compared to east or west.
- **Shape building for self-shading.** Building form can assist cooling by providing self-shading through wings and other mass articulations, balconies, deep reveals, or arcades.
- **Take a deep facade approach.** A facade with some depth creates a buffer zone that can contain shading elements and other modifiers to filter glare and block sun.
- **Capitalize on other building elements to integrate shading.** For example, overhangs, louvers, fins, and light shelves can be integrated both structurally and visually with the exterior structural system.
- **Incorporate envelope features that improve daylighting.** Deep reveals, splayed reveals, exterior fins, and similar characteristics of the envelope structure improve daylight distribution and control glare. These facade projections can also attenuate noise. Rounded edges soften light contrasts. Effective reveals are 9 to 12 inches (23-30 cm) deep, at an angle of 60˚ to the window plane.
- **Balance daylight admittance.** Spaces with windows on two sides often have better daylighting distribution.
- **Keep private offices somewhat shallow**. Keep depth of rooms within 1.5-2.0 times window head height for adequate illumination levels and balanced distribution.



Deep wall section provides self-shading, allows easy integration of light shelf, creates surfaces that mitigate glare, and reduces noise transmission. Sloped surfaces also help soften glare.





plan view of splayed window opening

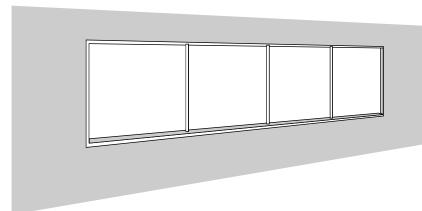
Sloped surfaces, such as this splayed window opening, help soften glare. These surfaces should be light-colored and provide an intermediate brightness between window and room surfaces, making an easier transition for the eye.

- **Consider color and texture of exterior surfaces.** Light-colored surfaces will reflect more daylight than dark surfaces. Specular surfaces (e.g., glazed tile or mirrored glazing) may create glare if viewed directly from an office. Diffuse ground-reflected daylight can increase daylight availability.

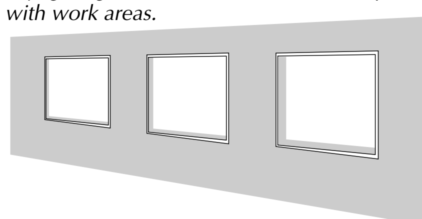
Windows

- **The higher the window, the deeper the daylighting zone**. The practical depth of a daylighted zone is typically limited to 1.5 times the window head height. With a reflective light shelf, this zone may be extended up to 2.5 times the head height. If a corridor is beyond this zone and separated with a partially glazed wall, it may be adequately lit with the spill light from the room. With standard window and ceiling heights, plan on adequate daylight within 15 feet (4.6 m) from the window.

- **Strip windows provide more uniform daylight**. The easiest way to provide adequate, even daylighting is with a nearly continuous strip window. Punched windows are acceptable, but the breaks between windows can create contrasts of light and dark areas. This is not a problem if work areas are paired with windows or if other glare measures are taken.

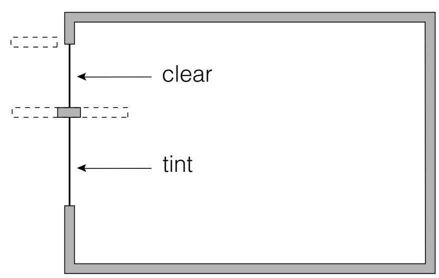


Strip windows are an easy way for uniform daylighting. Punched windows should be paired with work areas.



- **Large windows require more control**. The larger the window, the more important glazing selection and shading effectiveness are to control glare and heat gain. Use double pane to control winter heat loss and improve thermal comfort. See Tools & Resources for sizing help.

- **Size the windows and select glazing at the same time**. The larger the glass area, the lower the required visible transmittance. Use the effective aperture (EA) approach (see illustration on page 3-3). Select glazing and window area to target an EA around 0.30. See Tools & Resources for sizing help.



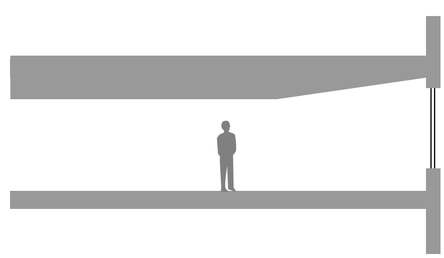
Different apertures for daylight and view: clear glazing above for maximum daylight, tinted glazing below for glare control. The structure between the two provides a visual break and an opportunity to attach a light shelf or shading device.

- **Keep occupants away from large areas of single-pane glass**. Avoid big windows very close to task areas since they can be a source of thermal discomfort.

- **Use separate apertures for view and daylight**. A good approach for excellent daylighting and glare control is the separation of view and light windows. Use high transmission, clearer glazing in clerestory windows, and lower transmission glazing in view windows to control glare.

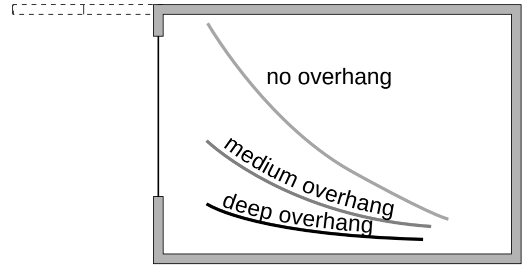
- **Position windows to direct light onto the ceiling**. For good distribution, use taller ceilings and high windows. Keep the ceiling smooth and light-colored. A sloped ceiling (high near the window) is one way to fit a high window within normal floor-to-floor heights.

- **Introduce more light-colored surfaces** for good distribution. Deep reveals, ceiling baffles, exterior fins and shelves, if they are light in color, keep daylighting more even.

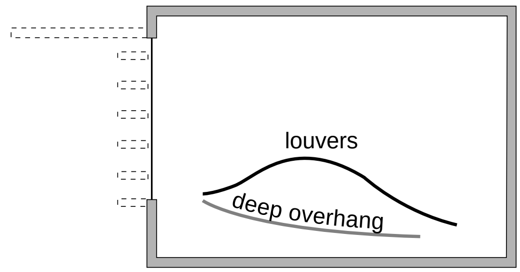


A sloping ceiling at perimeter raises the window head without increasing floor-to-floor height

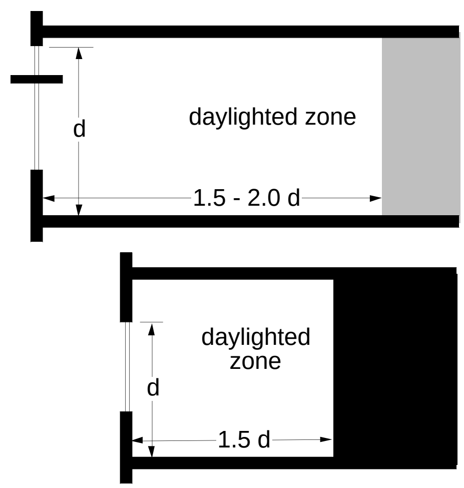
- **Incorporate shading elements with windows**. Shading devices perform triple duty: they keep out the sun's heat, block uncomfortable direct sun, and soften harsh daylight contrasts. See Section 5, SHADING STRATEGY, for more detail.
- **Use horizontal window shapes**. Horizontal shapes provide more even distribution—vertical windows are more likely to create light/dark contrasts, although taller windows mean deeper penetration. Long and wide windows are generally perceived as less glaring than tall and narrow ones of the same area. Occupants generally prefer wider openings when the primary views of interest are of nearby objects or activities.
- **Place view windows wisely**. Complex views with changing activities are preferable to static views. The key is the information content of the view and its ability to capture interest/attention. Sky alone is not a preferred view. Views that include the horizon are better.
- **Locate windows near room surfaces** (beams, walls) for good distribution—these surfaces help reflect and redistribute daylight.
- **Windows on every orientation can provide useful daylight**. However, treat each window orientation differently for best results.
    - North: High quality consistent daylight with minimal heat gains, but thermal loss during heating conditions and associated comfort problems. Shading possibly needed only for early morning and late afternoon.
    - South: Good access to strong illumination (the original source), although varies through the day. Shading is "easy".
    - East and West: Shading is difficult. Shading is critical for comfort on both sides and heat gain too, especially on the west. Windows facing generally north and south create the fewest problems.
- **Don't waste glazing area where it can't be seen**, such as below desk height. It wastes energy, causes discomfort (especially in winter), and provides little benefit.



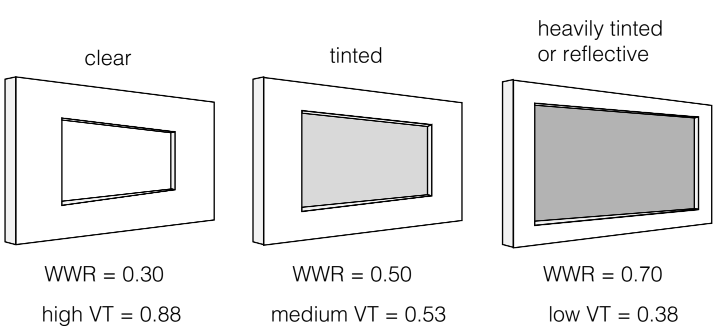
The curves indicate light levels. Overhangs reduce light and glare near the window, creating a softer gradient in the room.



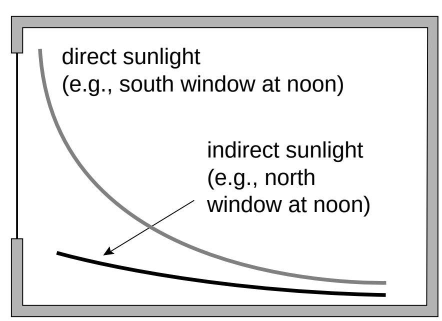
Break up the overhang for better distribution.



A rule of thumb for daylight penetration with typical depth and ceiling height is 1.5 times head height for standard windows, 1.5 to 2.0 times head height with light shelf, for south-facing windows under direct sunlight.



Effective Aperture (EA) is visible transmittance (VT) x window-to-wall ratio (WWR). These three windows all have the same EA.



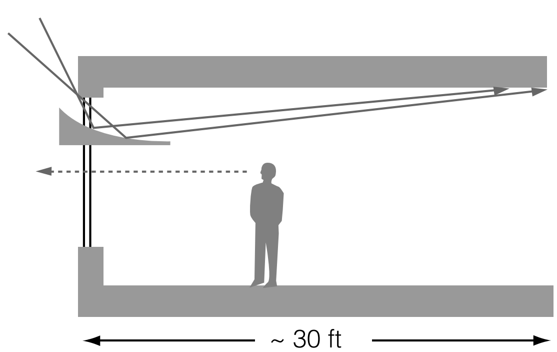
Curves show light levels when a window is facing the part of the sky that has the sun versus the sky away from the sun (daylight only, no direct beam in the room).

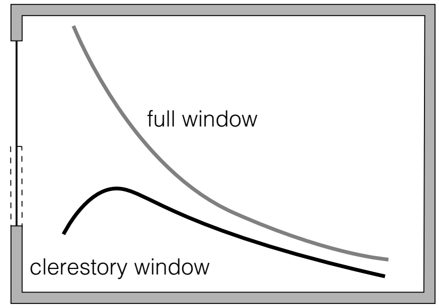
About Clerestories *(any window with sill above eye level)*

- Good for getting the light source out of direct sightline. Good for effective ceiling illumination (which provides deeper penetration and good distribution). Good for computer visual display terminals (VDTs) and other glare sensitive tasks.
- Loss of view—only view may be of the glaring sky.
- An effective approach is the use of high-reflectance blinds with clerestory glazing. A 1-foot-high (0.3 m) south clerestory with high-reflectance blinds can light a 150-square-foot (14 m²), 12-foot-deep (3.7 m) office, under sunny conditions.

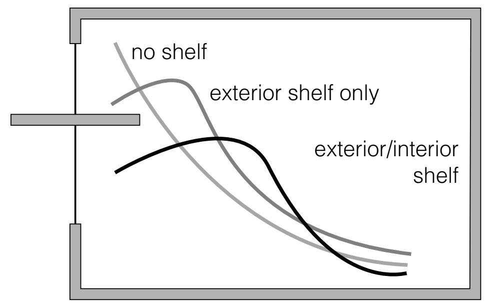
About Light Shelves *(horizontal elements above eye level)*

- Light shelves can improve illuminance distribution and reduce glare.
- Shelves double as shading devices, if designed to block direct sun.
- Best used on the south in a predominantly clear sky climate.
- Consider using clearer glass (with sun control) above for high daylight admission and tinted glass below for glare control.
- Exterior shelves are better than interior, but use both for best year-round distribution.
- The top of the shelf should be matte white or diffusely specular, and not visible from any point in the room.
- The ceiling should be smooth and light-colored.
- Consider using more advanced shapes and materials to redirect sun, block direct sun, and control glare (see Beltran et al. in REFERENCES section for ideas).

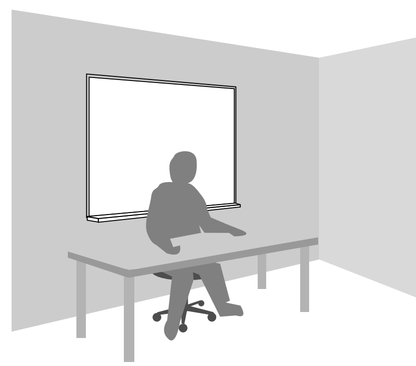




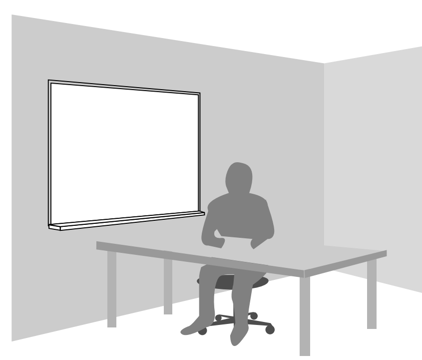
High windows provide better distribution. These curves indicate light levels. Notice the softer gradient with the clerestory.



A light shelf improves distribution of daylight. Notice the softer gradient with a light shelf.

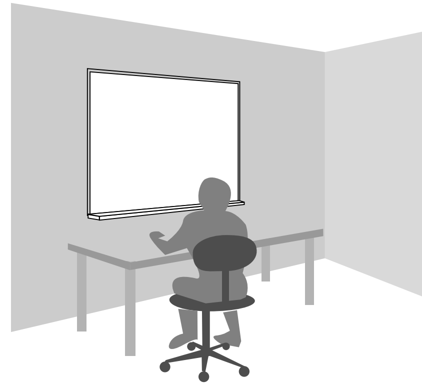


When the window is behind your back, you may shade your task and make it too dark to see easily. However, your computer screen may be difficult to see if it reflects light from the window.



The most comfortable seating is with the window to the side—task is well illuminated and the source is not in direct line of sight.

Space Planning



Facing the bright window creates a harsh contrast in comparison to your relatively dark task—this is very tiring for the eye to have both in the same field of view.

- **Locate activities according to light requirements.** Put rooms with little need for daylight (infrequent use, service, washrooms, VDTs) in non-perimeter areas. Locate tasks with higher lighting needs nearer the windows. Group tasks by similar lighting requirements for efficient use of electric lighting, and by similar schedules and comfort needs. Accommodate user preference and satisfaction when space planning is dictated by a worker's value to the organization (e.g., a high-level worker placed near the window).
- **Locate activities according to comfort requirements.** Place flexible tasks or low occupancy spaces where there may be unavoidable glare, not enough daylight, or direct sun penetration. These spaces may at times be thermally or visually uncomfortable. If tasks are fixed and inflexible, comfortable glare-free conditions are required.
- **Maintain daylight access.** Furniture layout should not block light for spaces farther from the window. Do not position full-height partitions, bookshelves, or files parallel to window wall if possible.
- **Use light-transmitting materials for partitions** where possible. Use clear or translucent materials in the upper portion of full-height partitions. If this approach is taken in corridor walls, corridors may be adequately lighted just by this spill light.
- **Shield occupants from views of highly reflective surfaces outside**, such as mirrored-glass buildings, water, snow, and large white surfaces.
- **Shield sensitive occupants from bright windows.** In highly glare-sensitive areas (e.g., with wide use of VDTs), shield occupants from view of sky and provide glare-controlling window coverings.
- **Keep reflected view of bright windows out of computer screens.** Be very careful where VDTs are placed. Either keep them away from windows or block the screen and occupant's view of the window. Use partitions or position the screen with the window to the side and slightly turned away from window.
- **Use west zones for service spaces.** Minimize use of exposed west zones as occupied work areas. Large areas of west glazing make for difficult daylighting, high cooling loads, and uncomfortable occupants.

Interior Design

- **Don't use large areas of dark color.** Generally avoid all dark colors except as accents, and keep them away from windows. Dark surfaces impede daylight penetration and cause glare when seen beside bright surfaces. For good distribution throughout the room, it is especially important that the wall facing the window be light-colored. Mullions or other solid objects next to windows should be light-colored to avoid silhouette contrasts. Keep sills and other reveal surfaces light to improve daylight distribution and soften contrast. Dark artwork can reduce daylight effectiveness.
- **Aim for recommended surface reflectances.** Desirable reflectances (Illuminating Engineering Society recommendations): ceilings >80%; walls 50-70% (higher if wall contains window); floors 20-40%; furniture 25-45%.
- **Choose matte over specular surface finishes.** Matte finishes are recommended for good distribution of daylight and no reflected glare (hot spots).
- **Use light-transmitting materials.** Translucent or transparent partitions are best when possible—daylight can pass through to other spaces.
- **Supply window coverings that allow individual control** to accommodate different glare tolerances. Interior window shading should be light-colored for best cooling load reduction.
- **Choose colors under the right light.** Choose interior colors and finishes under daylight and under the proposed electric lamps to avoid surprises in color rendering.

INTEGRATION ISSUES

Architecture

- Facade design must be driven by interior results as much as exterior appearance. Form, siting, and skin decisions strongly influence daylighting performance, cooling loads, and occupant comfort.

Interior

- In daylighted spaces, it is critical that light colors be dominant, especially for walls and ceilings.
- Window coverings should allow for some light penetration while providing sun and glare control.
- Interior design must consider the role of interior finishes and objects as light modifiers within a daylighted space—these factors influence daylighting performance.

HVAC

- High skin-to-volume ratio is good for daylighting but may adversely affect thermal balance.
- Use building form and exterior shading to best reduce peak cooling load—this can save on HVAC first costs. Consult with an engineer to establish magnitude and relative importance of envelope decisions.

Lighting

- Window design and exterior and interior modifiers determine the nature of daylight in the space. Lighting design and control strategy are critical.
- Interior colors, furniture placement and partition heights are critical to lighting design—make these decisions with lighting designer input.

Cost-effectiveness

- High skin-to-volume ratio is good for daylighting, but may not yield a high enough ratio of rentable space and may be more costly to construct.
- A deep or layered building skin is more expensive than thin cladding but offers long term benefits if used to best advantage for sun and glare control. Computer analysis of building performance along with careful cost estimates are required for determining cost-effectiveness.

Occupant Comfort

- The best lighting and mechanical systems can't make up for architectural errors with respect to perimeter zone comfort. Window and room design must provide for thermal and visual comfort of the occupant.
- Occupant satisfaction will depend on the fit between environment and task needs. Know the intended use of the space before design.

PROVISOS

- Dark tinted glazings diminish the capacity to daylight.
- Don't forget to look into lighting controls—their absence will not allow you to increase energy efficiency. (Be sure to work through the remaining sections of these guidelines.)

TOOLS & RESOURCES

Determining Required Net Glazing Area

- **Use this as a starting point for estimating required window size**. Alternatively, use the equation to roughly find the average daylight factor (indoor horizontal illuminance divided by outdoor horizontal illuminance) for a given window size. The equation assumes a rectangular room whose depth is no more than 2.5 times window head height. It also assumes an overcast sky. For regions with predominantly clear skies, window area can be smaller than calculated here.
- **The equation below yields the required net glazing area**. To translate this to total window area, which includes framing and mullions, multiply by 1.25.

$$\text{Required Net Glazing Area} = \frac{2 \times \text{Average Daylight Factor} \times \text{Total Area of Interior Surfaces} \times \left(1 - \text{Area-Weighted Average Reflectance of all Interior Surfaces}\right)}{\text{Visible Transmittance} \times \text{Vertical Angle of Sky Visible from Center of Window}}$$

- **Average Daylight Factor**. Use:

  1 if low-light spaces are desired

  2 if average spaces are desired

  4 if bright spaces are desired

- **Total Area of Interior Surfaces**. Add up total surface area of walls, ceiling, and floor.

- **Area-Weighted Average Reflectance**. Ratio between 0 and 1. Add up total surface area of walls, ceiling, floor, windows, partitions, and furniture, and calculate weighted average reflectance (see equation), or

$$\text{Area-Weighted Average Reflectance} = \frac{\text{Wall Area} \times \text{Wall Reflectance}}{\text{Total Surface Area}} + \frac{\text{Ceiling Area} \times \text{Ceiling Reflectance}}{\text{Total Surface Area}} + \text{...etc.}$$

  use 0.5 as default.

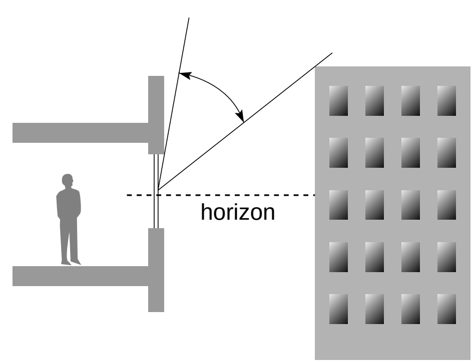
- **Visible Transmittance**. See V_T Table in Section 2, DAYLIGHT FEASIBILITY, or use:

  0.70 for small windows

  0.50 for medium windows

  0.30 for large windows

- **Vertical Angle of Sky**. Estimate the angle as shown, from center of window. Value between 0 and 90. If no obstruction, vertical angle is 90˚.



Vertical Angle of Sky

Source: "A Sequence for Daylighting Design," J. Lynes, *Lighting Research and Technology*, 1979.

Four methods to quantify daylighting levels and energy impacts

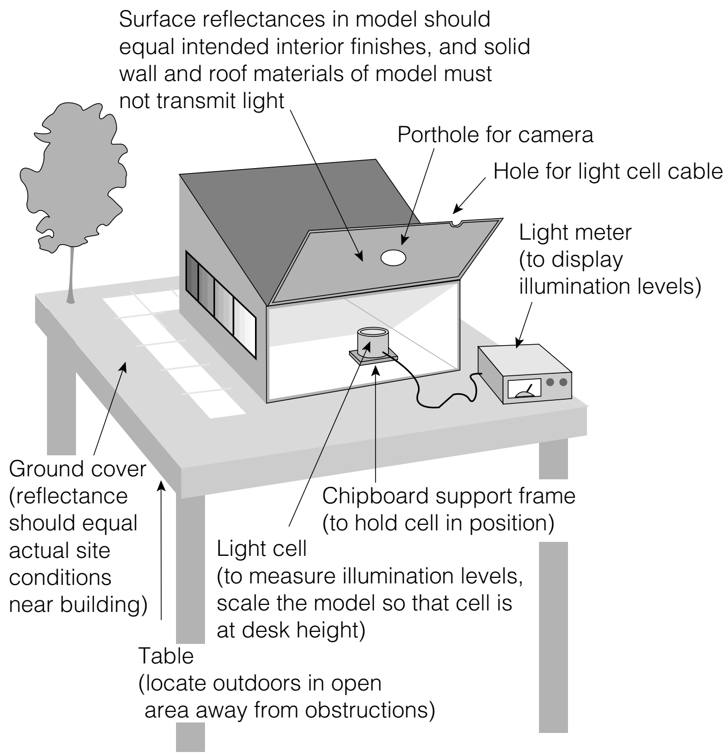
1. **Scale Model.** A physical model is a simple, quick, and inexpensive tool for determining approximate daylight levels in a space and is useful at all stages of design. A rough assessment of how well the design mitigates glare and controls direct sun can also be made. Models are helpful for fine tuning decisions, for convincing clients, and for flagging potential construction problems.

   a. Ensure materials and joints are opaque—cover joints with black tape; paint or cover exterior surfaces if not opaque. Note: White foamcore is not opaque and needs to be covered with opaque material.

   b. Be sure to model all 3D features of the windows, like sills and reveals.

   c. Glazing can be left out if you don't have a sample of the actual glazing, but see item *i.* below. If diffusing materials are intended, use tracing paper or a uniformly translucent plastic for glazing.

   d. If possible, build in a modular fashion to allow easy variations. Scale: 1"=1' for small rooms, 1/2"=1' for larger rooms.



Scale models studied outdoors show the quality of lighting, flag glare problems, and provide measured daylight readings.

Source: *Concepts in Architectural Lighting,* by M.D. Egan, McGraw-Hill, 1983.

   e. Cut a porthole in the sidewall adjacent to window for eye and camera.

   f. Take outdoors, preferably to actual site or some place where sky exposure and obstructions are similar, position in proper orientation, and observe interior for several minutes as your eye adapts to the lower interior illuminance level. Qualitatively assess four things: character of the space, adequacy of illumination, glare, and balance across the room depth. Be sure to measure under an appropriate variety of sun and sky conditions (e.g., clear, overcast, etc.).

   g. Take photographs with a wide-angle lens and fast film—results are highly realistic and helpful for analysis later. Black and white film is recommended if model colors are not the intended final colors.

   h. Add furniture and other details for realism and scale. If you have access to photometric equipment, measure illumination and calculate daylight factor (horizontal indoor illuminance divided by horizontal outdoor illuminance) for several different task locations.

   i. If you have not included glazing in the model, multiply your readings by the visible transmittance of intended glazing.

   j. Ask at local utility or architecture school for possible assistance. Otherwise, see books listed below for more tips.

2. **Daylighting Calculations by Hand.** This is an alternative to photometry in a scale model, when it's important to quantify daylight illumination levels. Several standard procedures exist. A lighting designer should be familiar with them. Or obtain instructional literature (see sources below).

3. **Computer Daylighting Models.** Daylighting software typically delivers faster, more accurate results than illumination calculations done by hand. Consult a lighting designer or request a "Daylighting Design Tool Survey" from the Windows and Daylighting Group at Lawrence Berkeley National Laboratory (510-486-5605).

4. **Engineering Software.** Refine window sizing, early glazing decisions, building form, and siting with preliminary mechanical load calculations. See the list of energy analysis software in the Mechanical Coordination section of these guidelines.

Other Resources

- **IES** Contact the Illuminating Engineering Society at (212) 248-5000, ext. 112 for publications on daylighting, or visit the IESNA world wide web site at http://www.iesna.org.
- **ASHRAE** The American Society of Heating, Refrigerating, and Air Conditioning Engineers offers a wide range of reference materials. Call (800) 527-4723 for a publications list, or visit the ASHRAE world wide web site at http://www.ashrae.org.
- **Utility Company.** Inquire at local utility about possible incentives and design assistance.
- **Books**

  Concepts in Architectural Lighting, by M. David Egan (McGraw-Hill, 1983) has a helpful section on window and interior design.

  Concepts and Practice of Architectural Daylighting, by Fuller Moore (Van Nostrand Reinhold, 1985) is an excellent and thorough resource. Includes a good treatment of basic principles.

  Daylighting Performance and Design, by Gregg D. Ander (New York: Van Nostrand Reinhold, 1995)

  Sunlighting as Formgiver for Architecture, by William M.C. Lam (New York: Van Nostrand Reinhold, 1986)

- See annotated TOOLS & RESOURCES SUMMARY for additional sources.

☑ CHECKLIST

1. Know the true north orientation of the site and include it on all plan drawings. Lot property lines are typically given relative to true north.
2. If the site allows, the first attempt at building placement should be with the long axis running east-west.
3. Minimize apertures on the east and especially the west. Low sun angles for these orientations makes shading extremely difficult without blocking the entire window.
4. Study the potential for (a) an articulated form that yields a high percentage of perimeter space, (b) an envelope structure and cladding that can integrate shading, and (c) opportunities for the building to shade itself.
5. Develop initial thoughts about shading strategy and glazing type.
6. Determine whether your project budget will allow consideration of a light shelf or exterior projecting shading elements.
7. Begin window design with both interior considerations and exterior appearance concerns simultaneously. Place windows primarily to provide view and light. Size and place windows for best glare-free daylighting with minimal energy penalty. A mechanical engineer should perform preliminary calculations at this point to help in window design and to determine the importance of glazing and shading decisions yet to come. If a light shelf or exterior shading are under consideration, include these elements in the calculations.
8. Build a rough model to study daylighting effects with the proposed skin, ceiling height, and room depth.
9. Interior design should begin selecting light colors for finishes and window coverings. Remember that rendering of interior colors will be affected by glass color.
10. Identify which occupant tasks best benefit from daylight before laying out task locations on floors. Put tasks requiring low, uniform light levels or with periodic occupancy (e.g., telephone closet) in the building core.
11. Discuss daylighting concepts with lighting designer or consultant to ensure that electric lighting layout and controls address daylight needs at the start of the lighting design process.
12. Check coordination issues with lighting, structural, and mechanical design. Keep ceiling as smooth and high as possible.

If you have...

no time

1. Minimize window area on east and especially on west.
2. Keep window area to a 30-40% window-to-wall ratio.
3. If tenants are unknown, use a strip window.
4. If tenants are known and punched windows are used, plan task areas to correspond with windows.
5. Keep interior finishes light-colored.
6. Try to increase surface area of window opening and splay these surfaces if possible.

a little time

In addition to above:

1. If preliminary glazing decision has been made, use engineer's early calculations to refine window area.
2. Explore envelope alternatives that could incorporate shading elements or light shelves.
3. Build a simple model and view it outdoors for lighting quality and glare.

more time

In addition to above:

1. Build a more accurate model and view/photograph outdoors. If photometric equipment is available, measure the daylight in the model. Refine design as necessary.
2. Mechanical engineer models variations in siting, form, footprint, and skin materials in an optimization study. Engineer looks for equipment downsizing opportunities.
3. Hire a daylighting consultant or investigate computer design tools.